Interannual Variability in MLS Trace Gas Observations in the Antarctic Polar Vortex: Issues in Detection and Attribution of Trends

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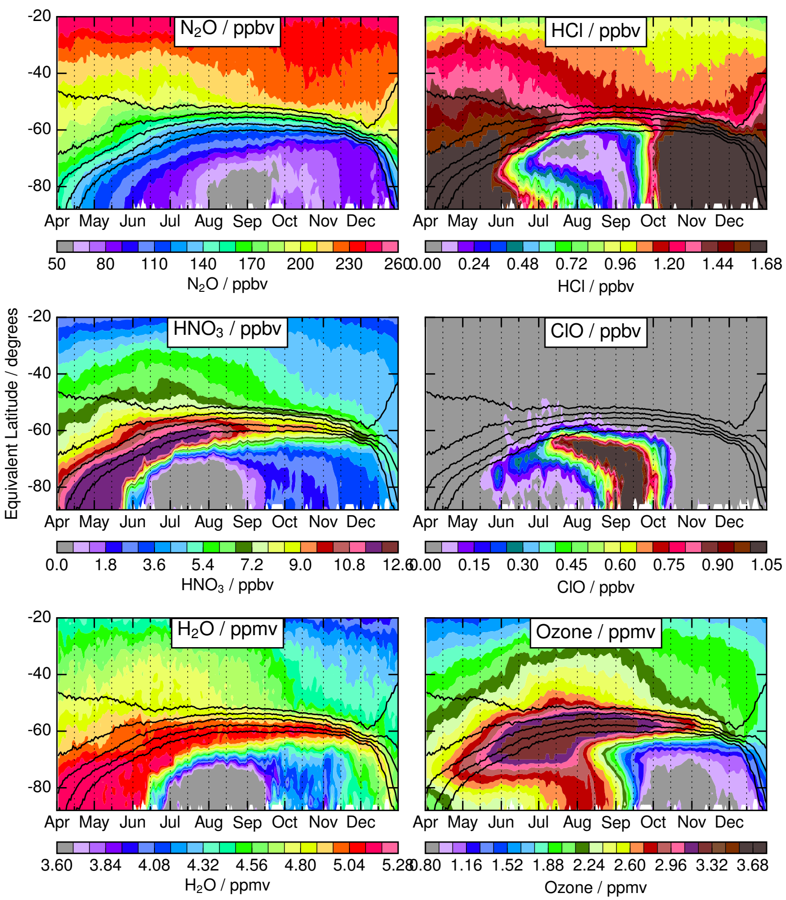
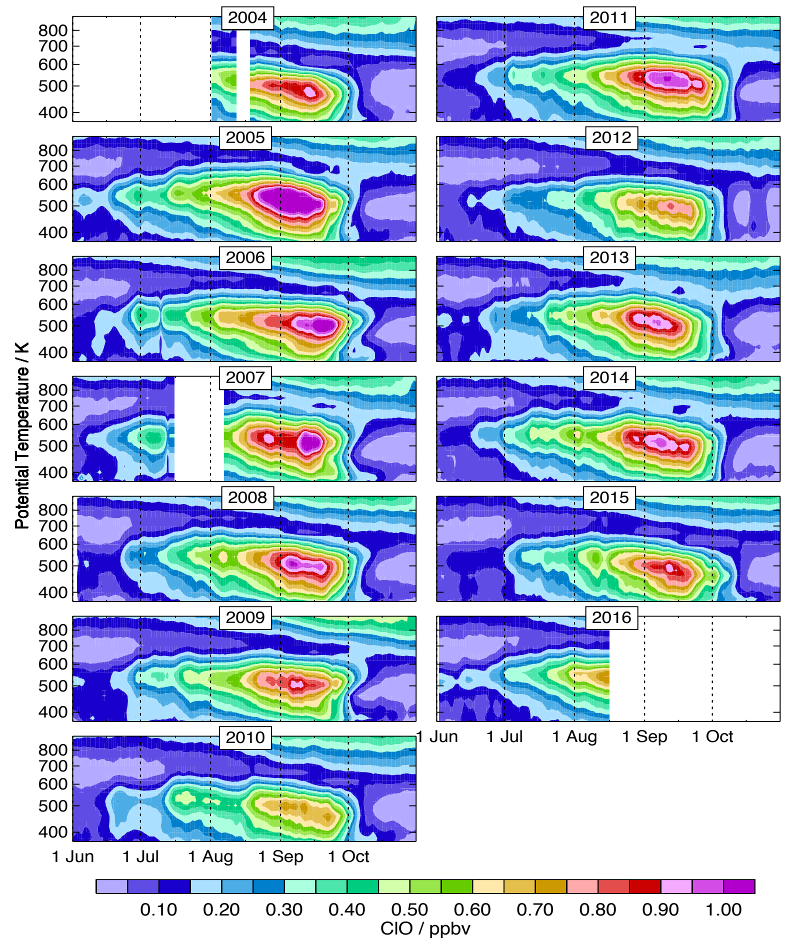
Among the primary science objective of Microwave Limb Sounder (MLS) on Aura is: ***to track the stability of the stratospheric ozone layer.***

We now have 12 years of vertically-resolved, daily, global, MLS measurements of ozone and other constituents providing insight into catalytic ozone destruction.

2015 MLS fields at 490K (~56 hPa, ~18 km)



MLS vortex-averaged ClO

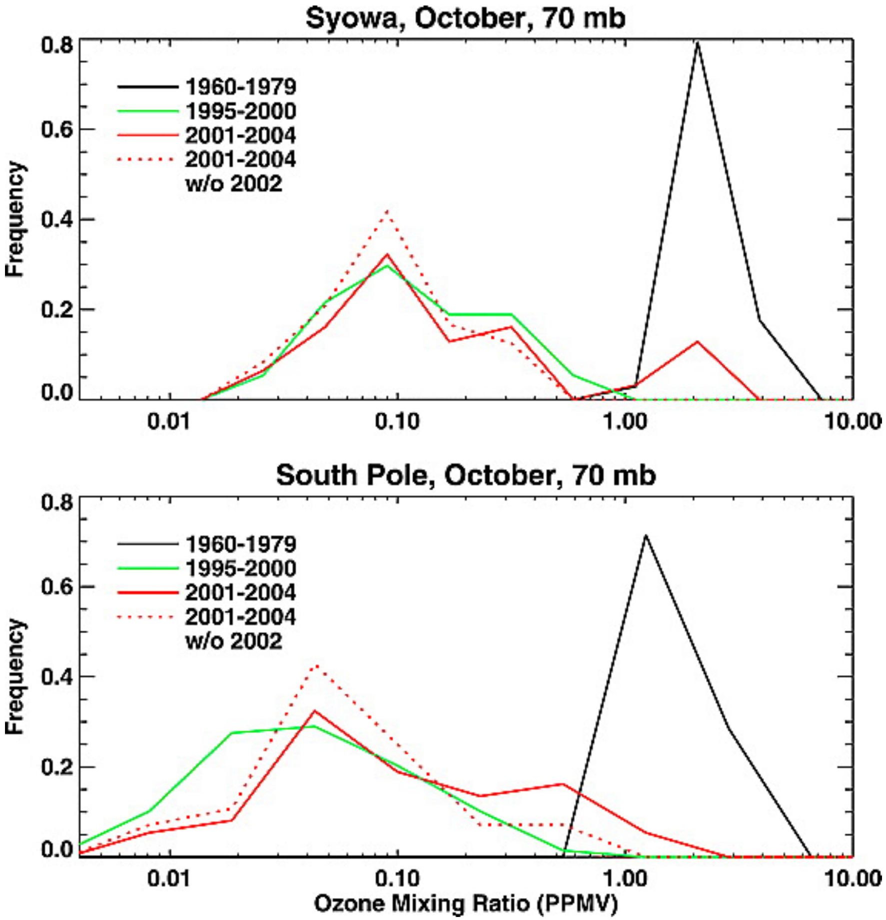


Motivation

- Given the decline in ODSs in the stratosphere and the availability of the high-quality, long-term MLS data record, we are at the threshold of plausibility for detection of Antarctic ozone recovery.
- A central challenge in detection of ozone recovery is the attribution of observed trends in ozone to changes in ODSs.
  - There are many interannually varying confounding factors (chemical, dynamical, and microphysical) besides declining ODSs.
  - Significance of inferred trends can depend substantially upon how data is “sliced”.
  - We must be vigilant against the urge to see what we want to see (and to stop looking when we “find” it).
- We have recently proposed to NASA to analyze the MLS record in this light, accounting for interannual variability in quantities such as wave forcing; descent rates; mixing; vortex permeability, shape, and sunlit area; volcanic aerosol; and temperature.
- This talk previews some aspects of the proposed work, but will focus on the 12-year MLS Antarctic spring ozone record and whether significant trends in the prevalence of low values can already be discerned from background variability.

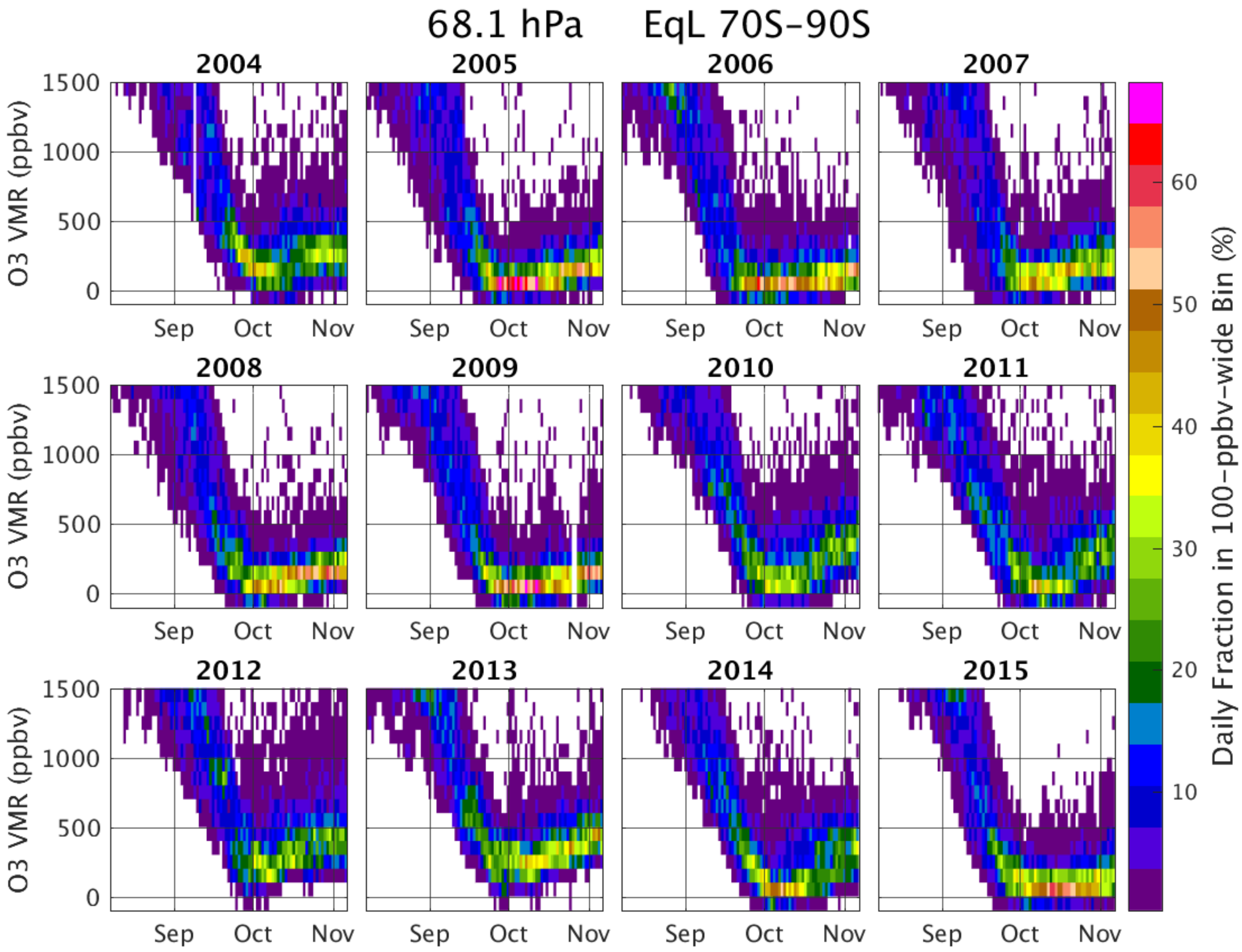
Insights gained from analysis of minimum abundances

- The Antarctic ozone hole has been characterized by near complete destruction of ozone in the spring lower stratosphere (18–20 km, 70–50 hPa).
- “Saturation” of the ozone destruction process results in particularly robust signals at abundances close to zero.
- *Solomon et al.* [2005] suggested monitoring the incidence of these extremely low ozone mixing ratios (minima and variances of PDFs) as indicators of recovery.
- Jos de Laat has been taking this a step further, performing trend analysis directly on histograms of MLS ozone, and we acknowledge inspiration from interactions with him related to these analyses.

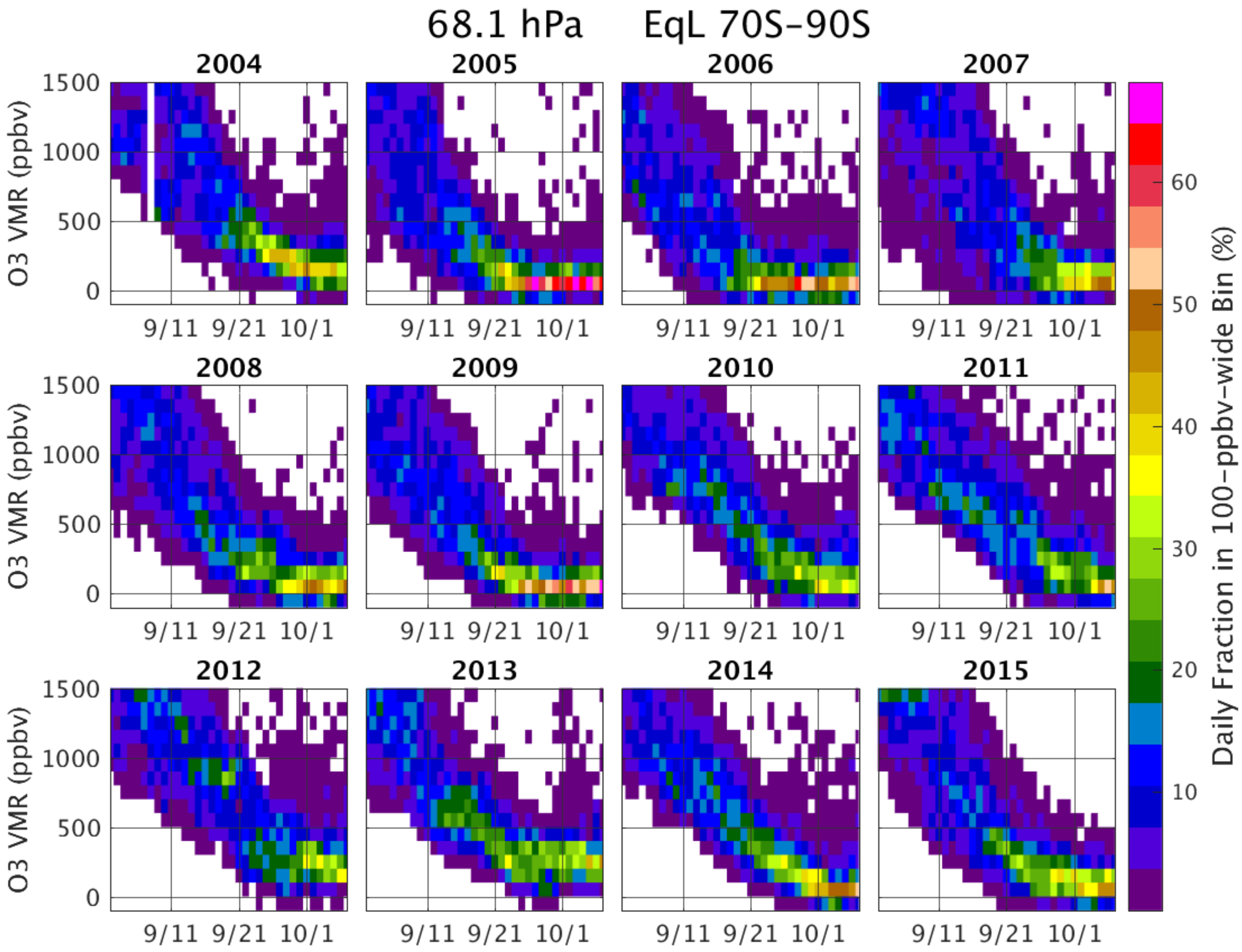


Solomon, et al. 2005
Journal of Geophysical Research: Atmospheres
Volume 110, Issue D21, D21311, 12 NOV 2005 DOI: 10.1029/2005JD005917
http://onlinelibrary.wiley.com/doi/10.1029/2005JD005917/full#jgrd12151-fig-0004

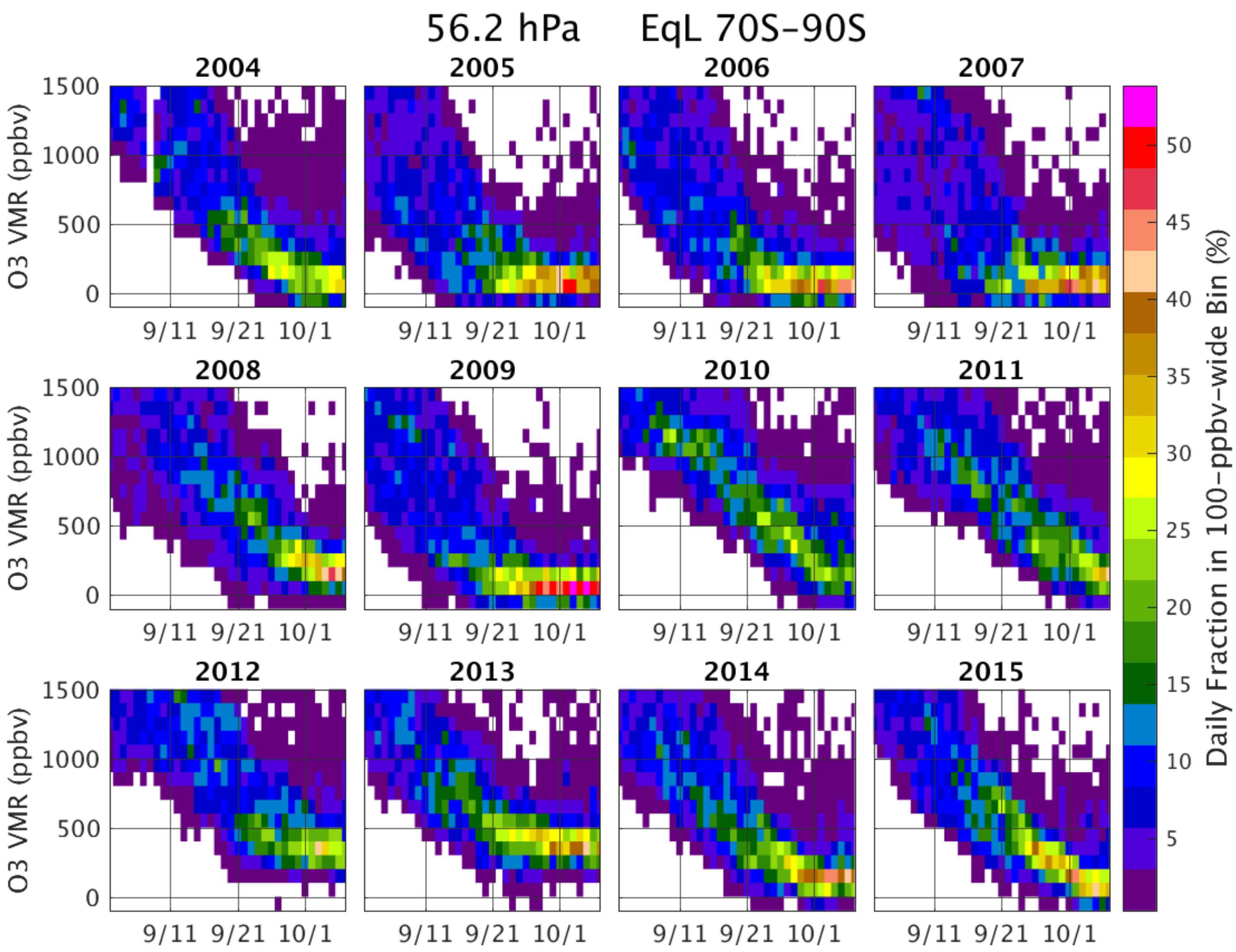
Daily ozone histogram timeseries at 68 hPa



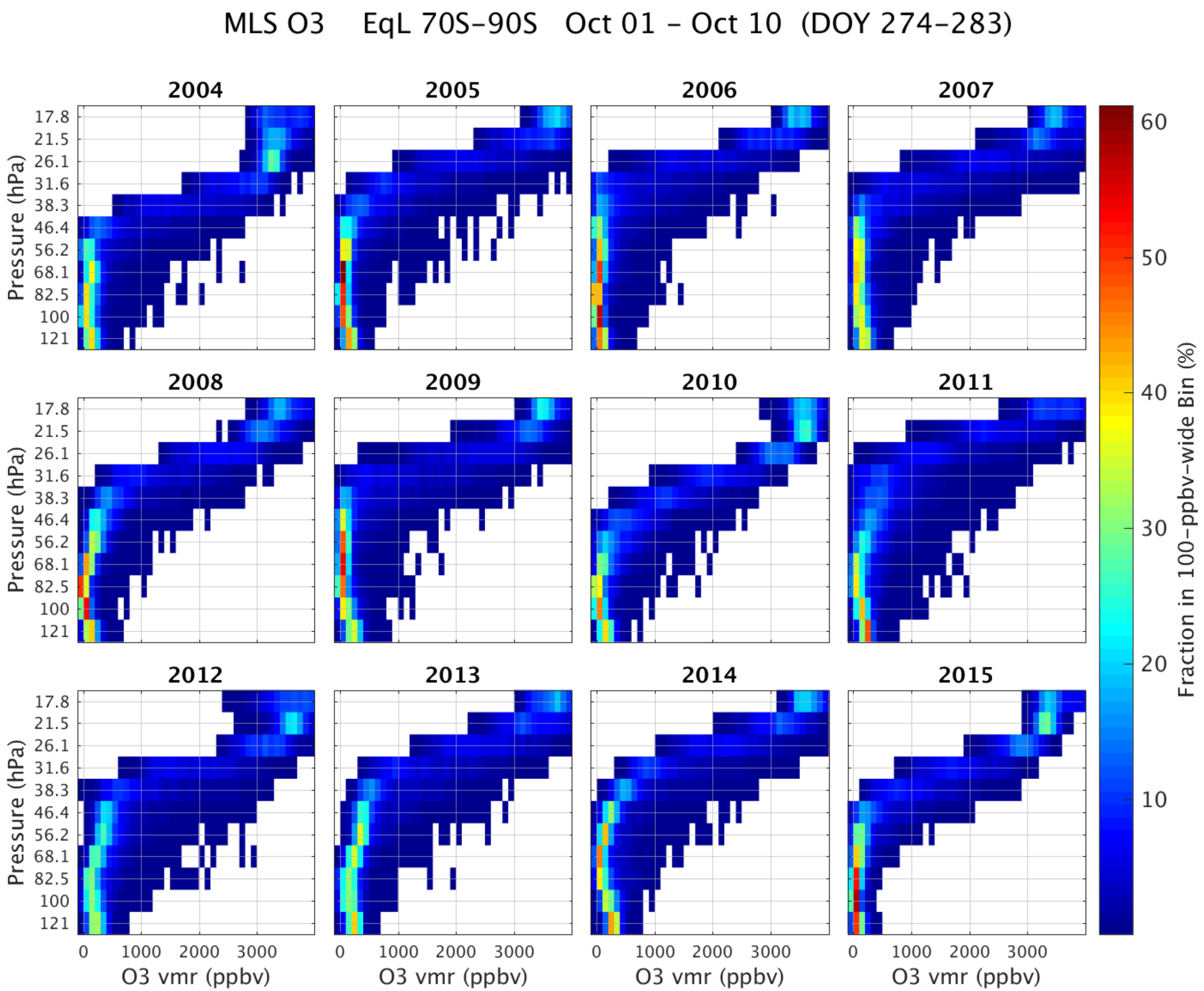
September / early-October timeseries at 68 hPa



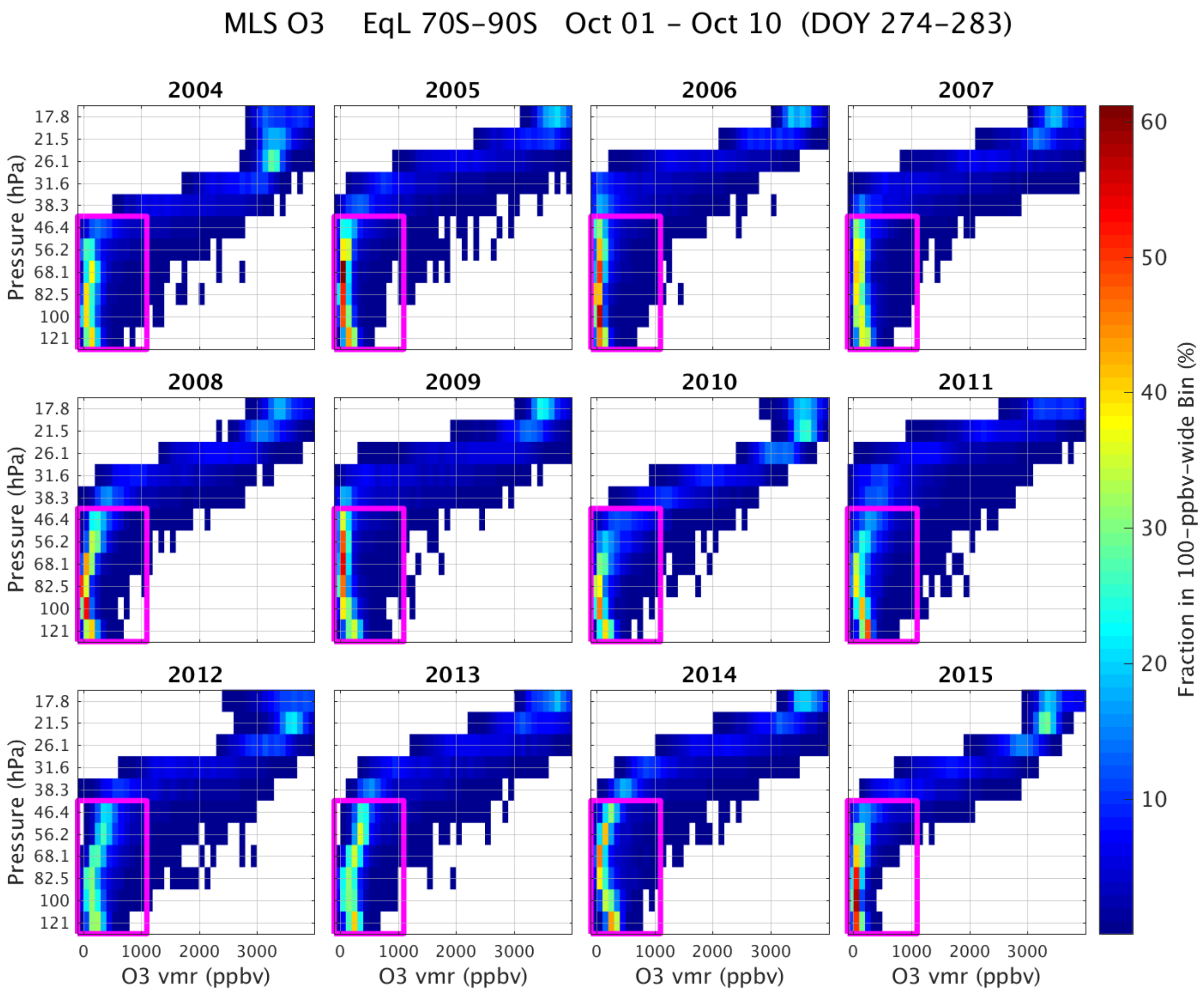
September / early-October timeseries at 56 hPa



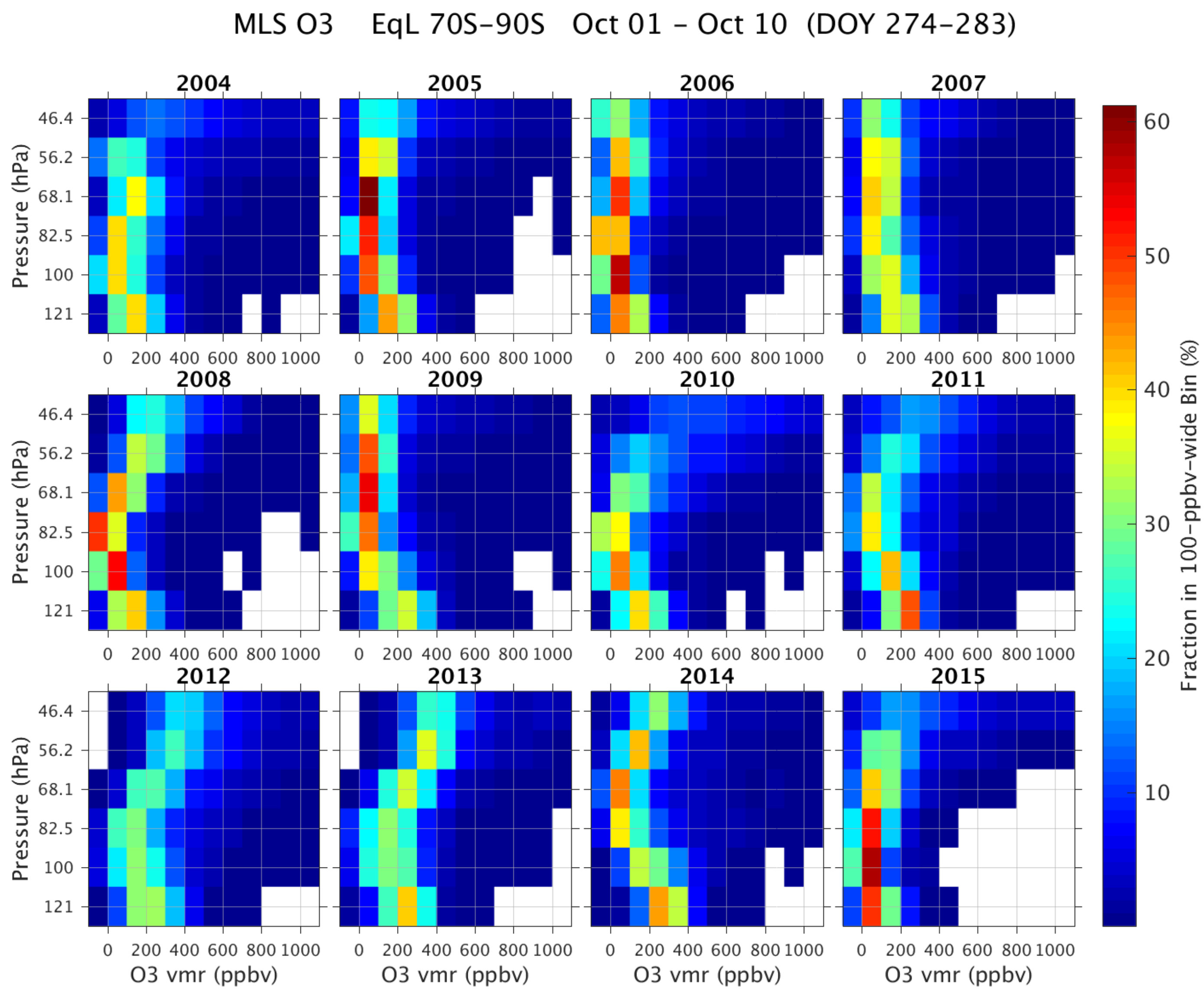
Ozone histograms limited to first 10 days of October



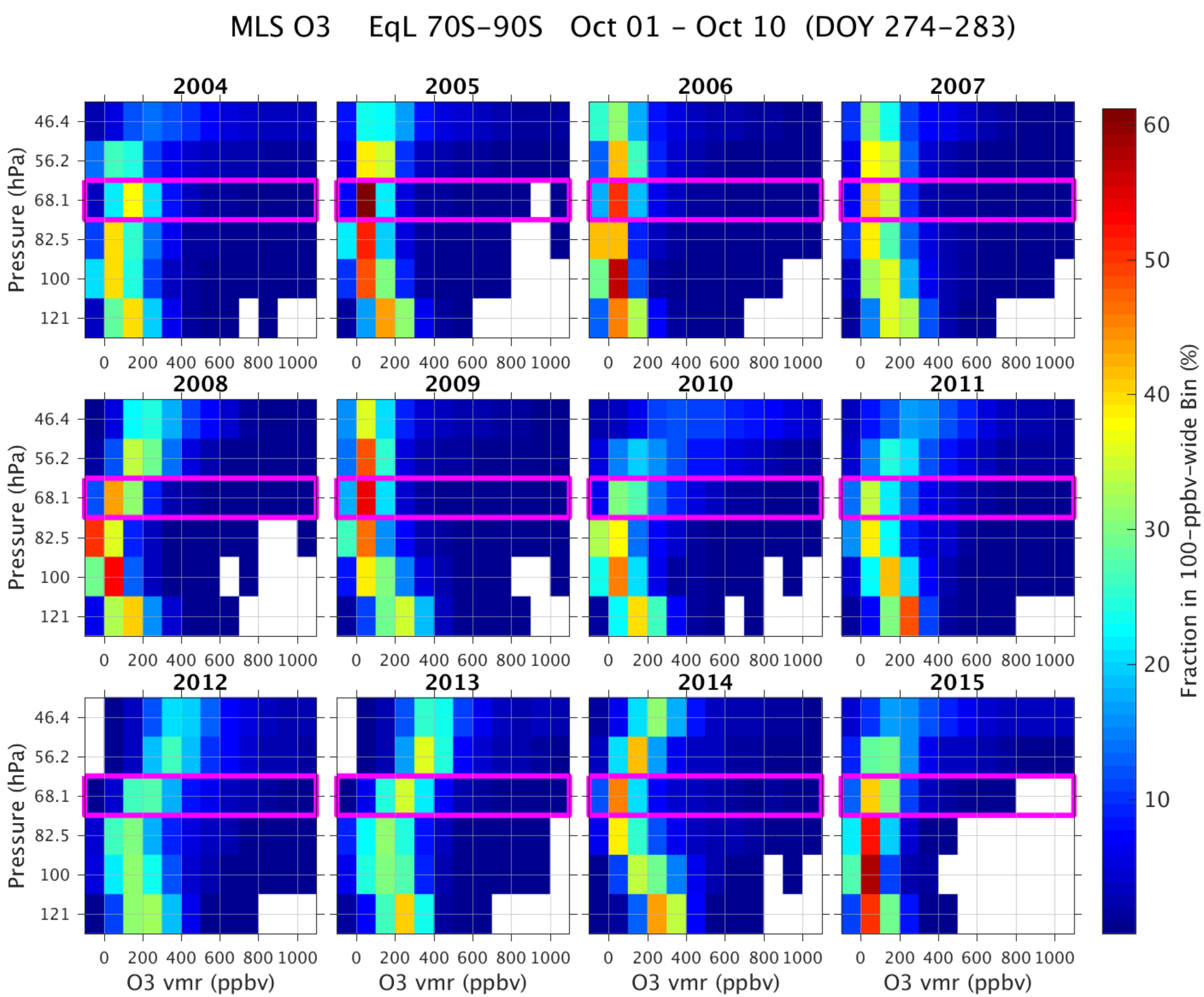
Ozone histograms limited to first 10 days of October



Zoom in on lowest-abundance histogram bins

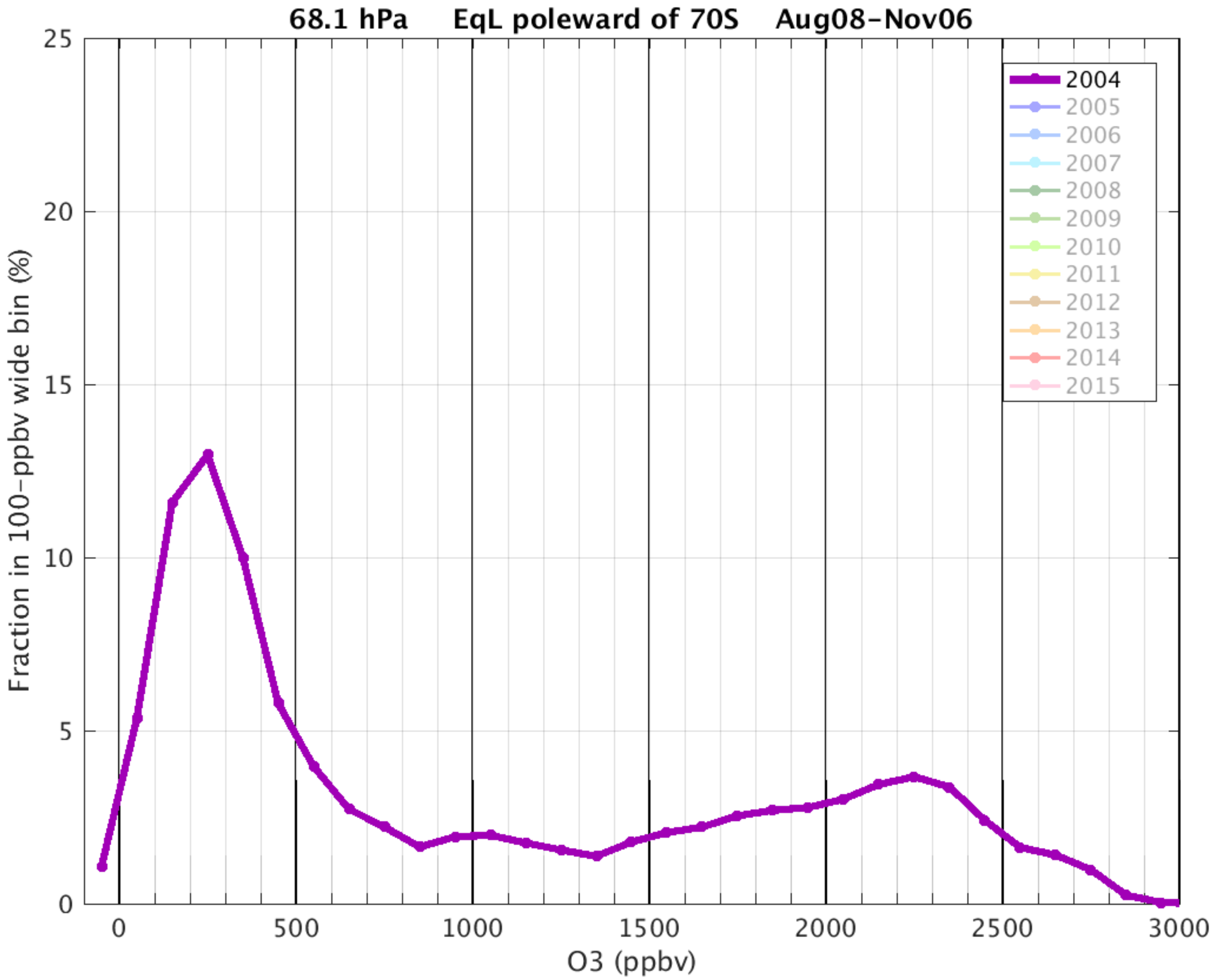


Zoom in on lowest-abundance histogram bins



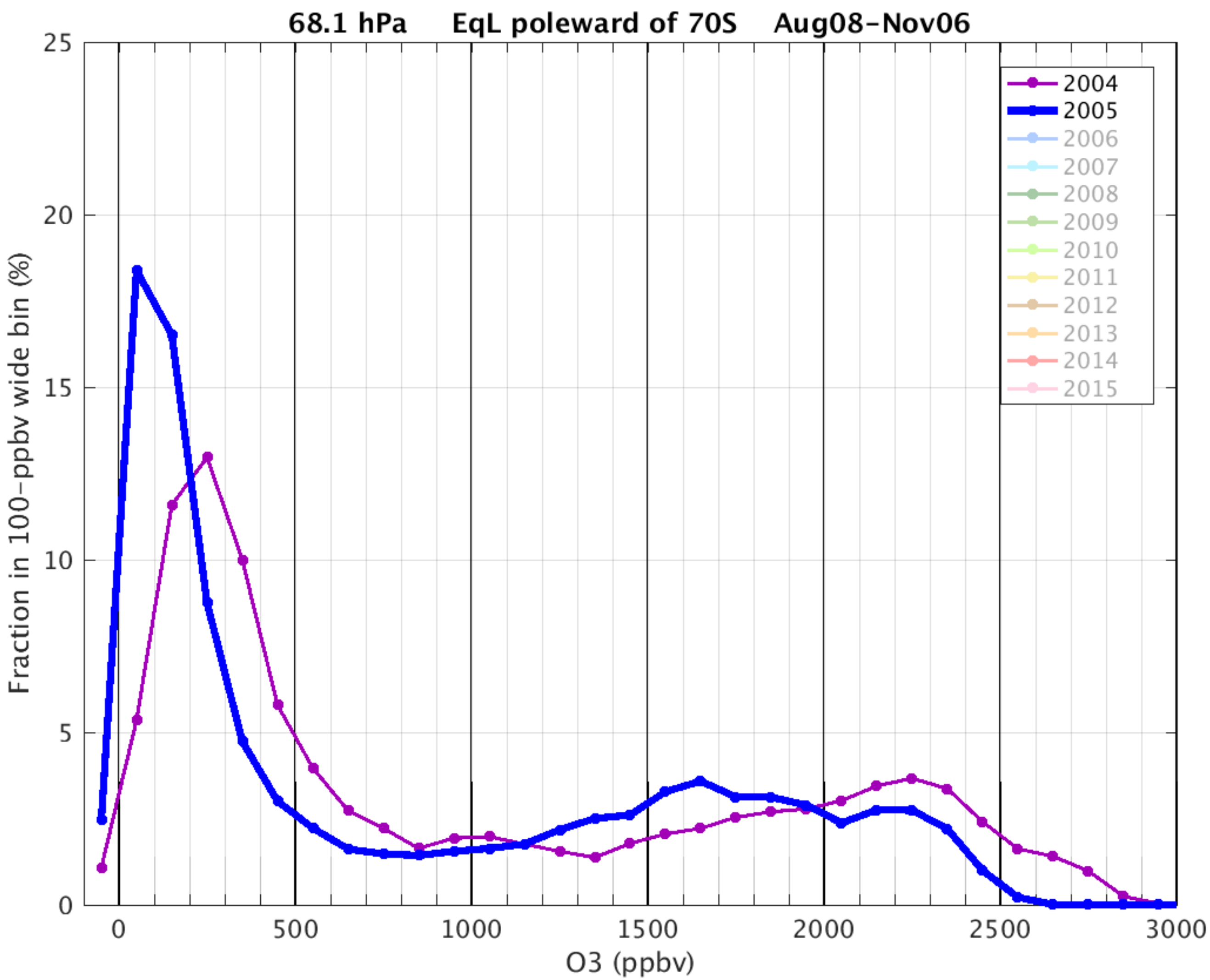
68 hPa Histogram summed over entire 91-day seasonal window

2004



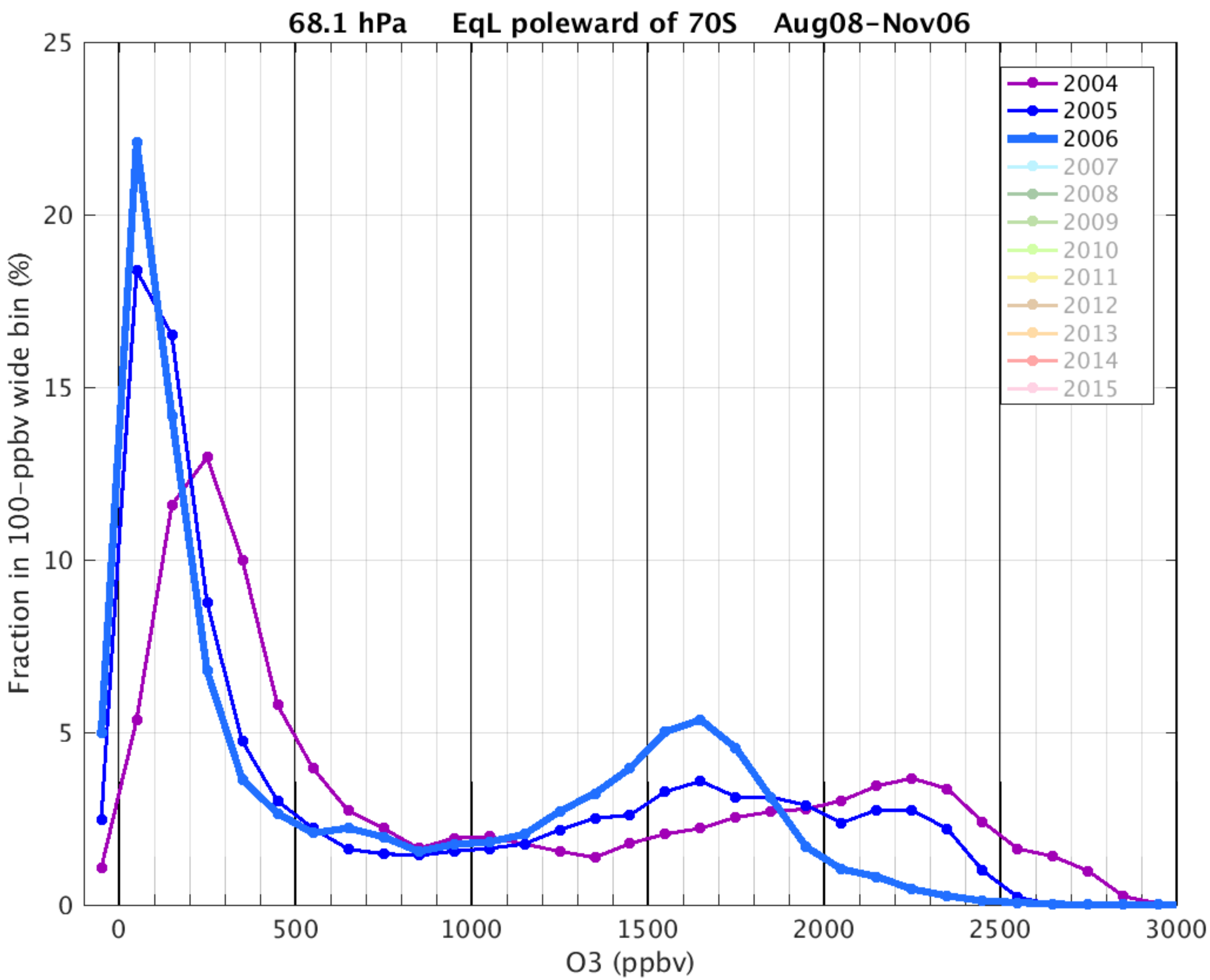
68 hPa Histogram summed over entire 91-day seasonal window

2004 – 2005



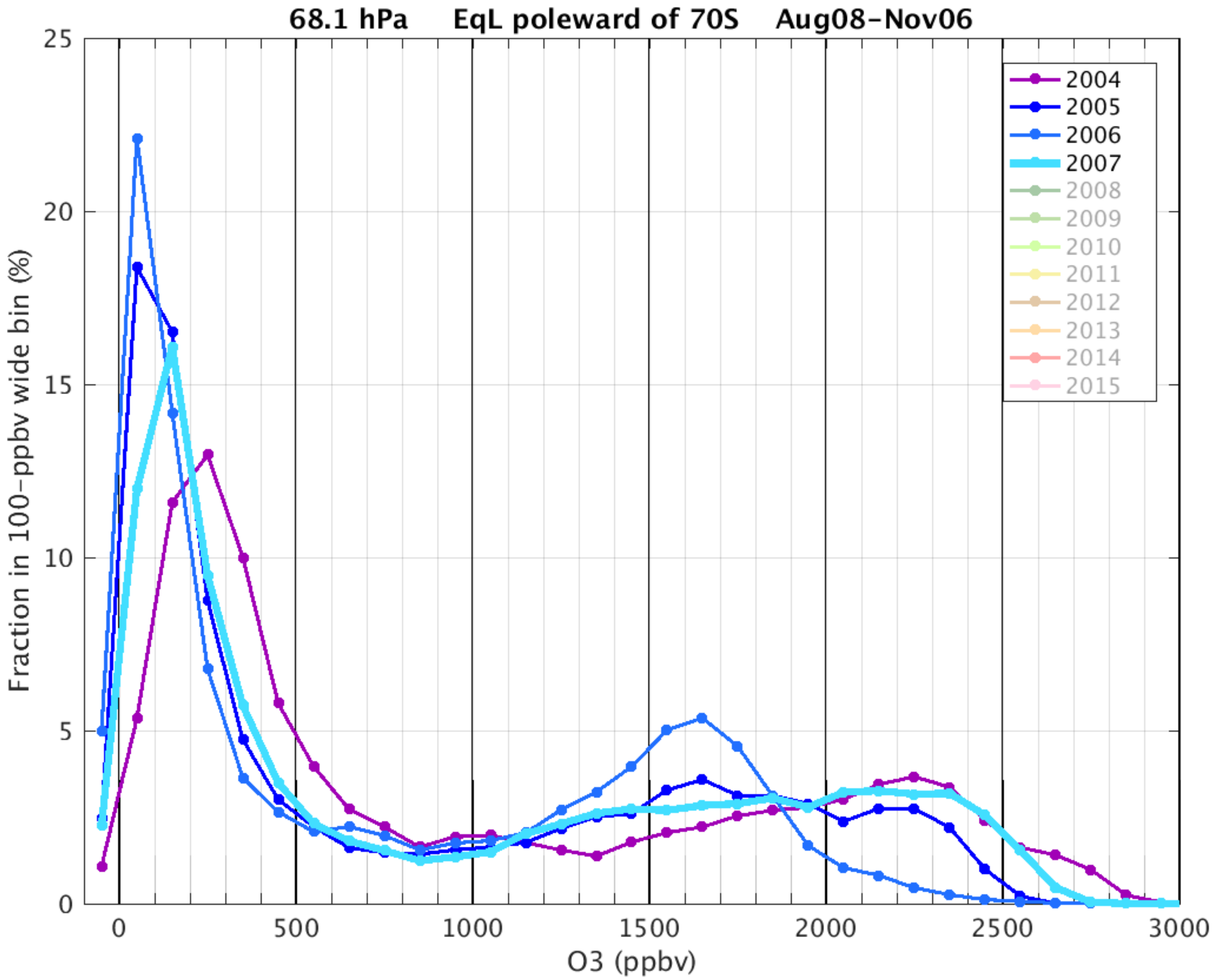
68 hPa Histogram summed over entire 91-day seasonal window

2004 – 2006

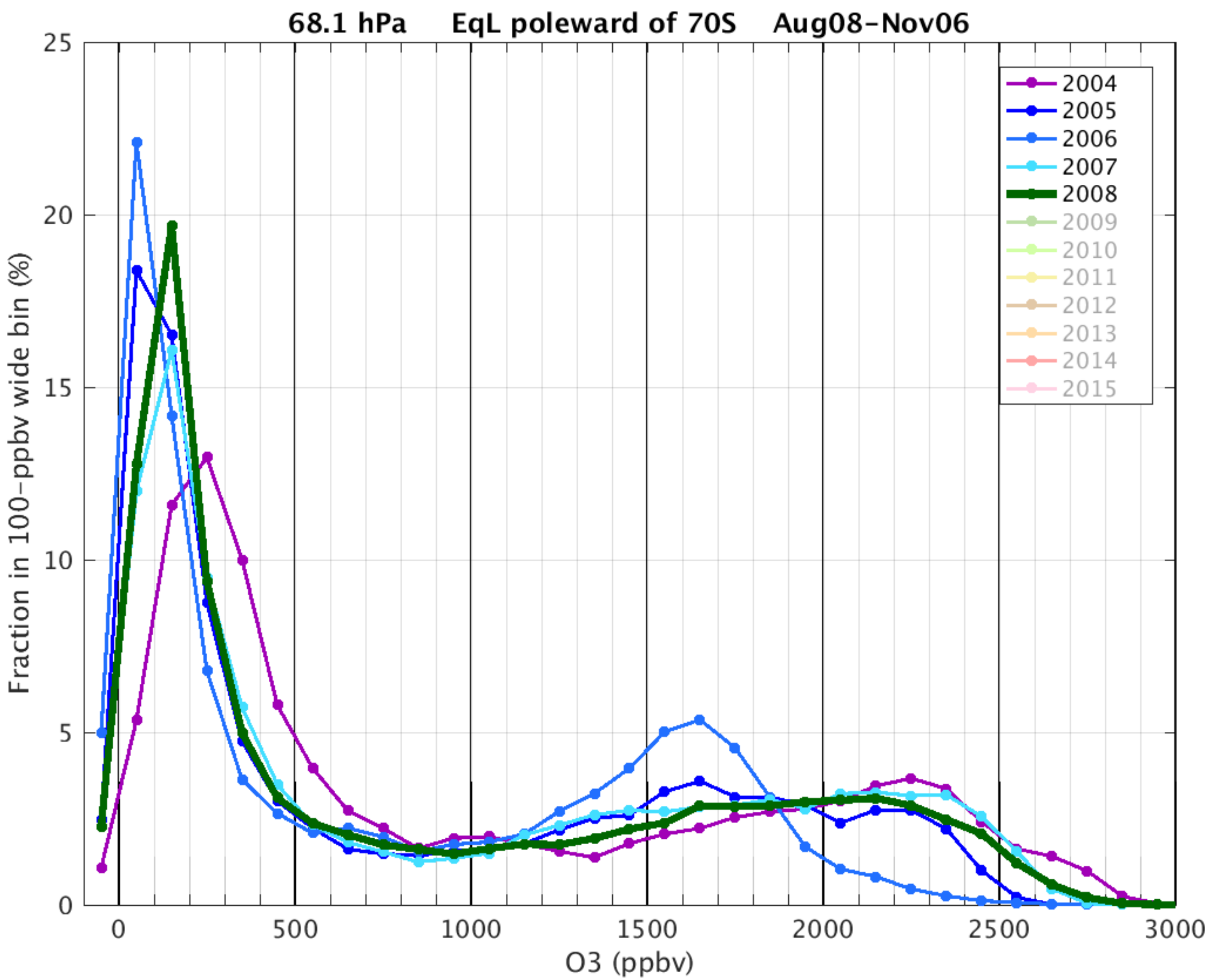


68 hPa Histogram summed over entire 91-day seasonal window

2004 – 2007

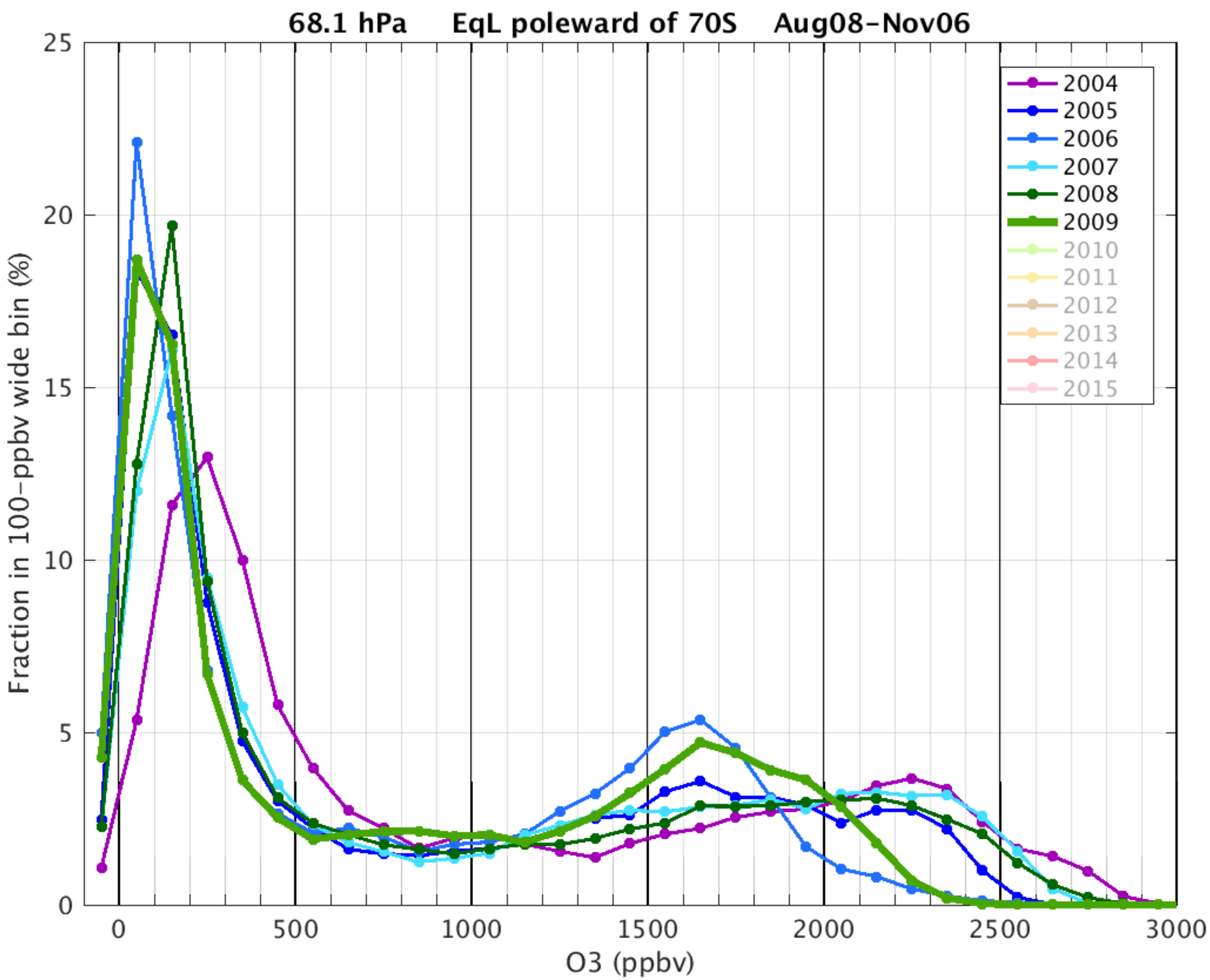


68 hPa Histogram summed over entire 91-day seasonal window
2004 – 2008



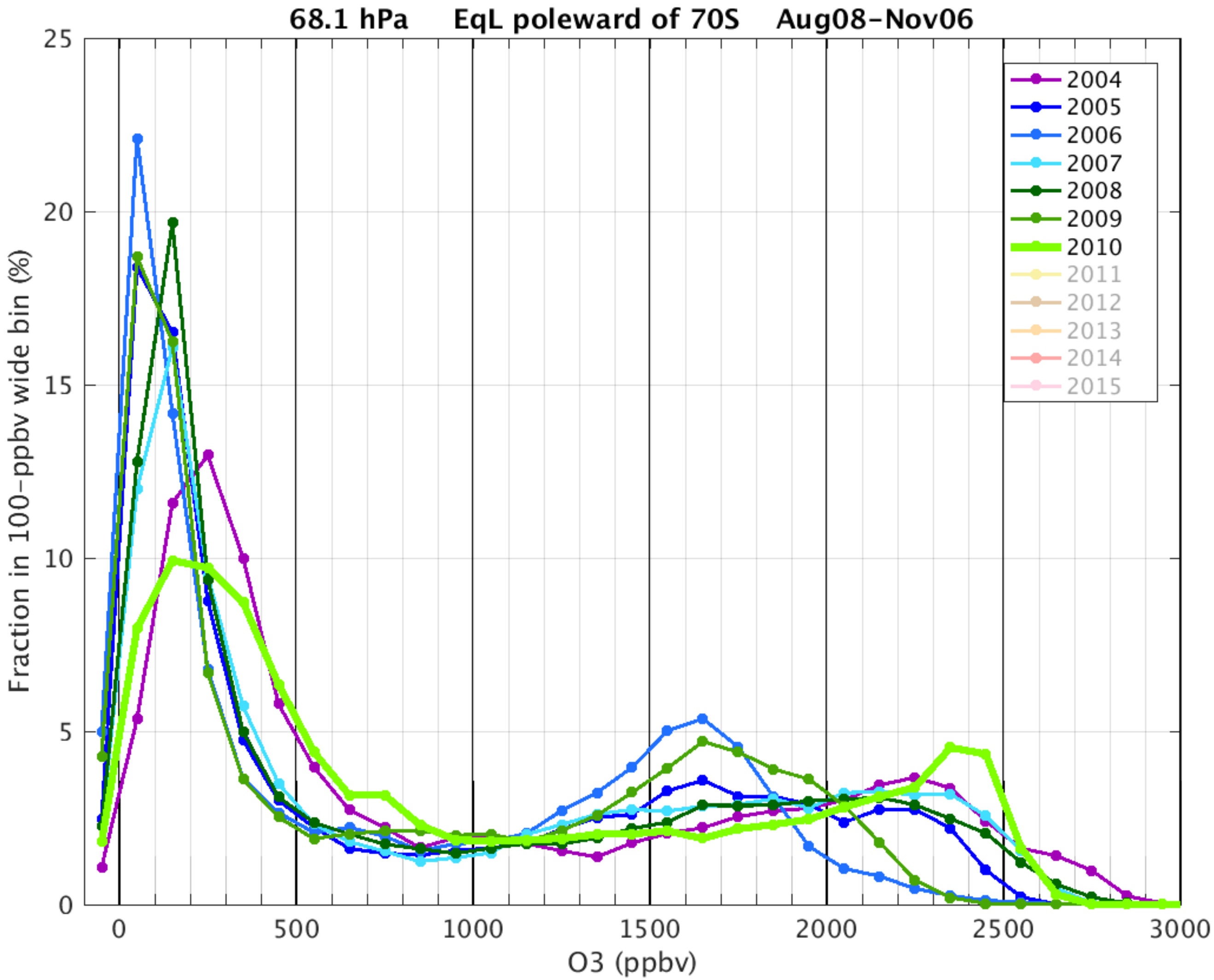
68 hPa Histogram summed over entire 91-day seasonal window

2004 – 2009



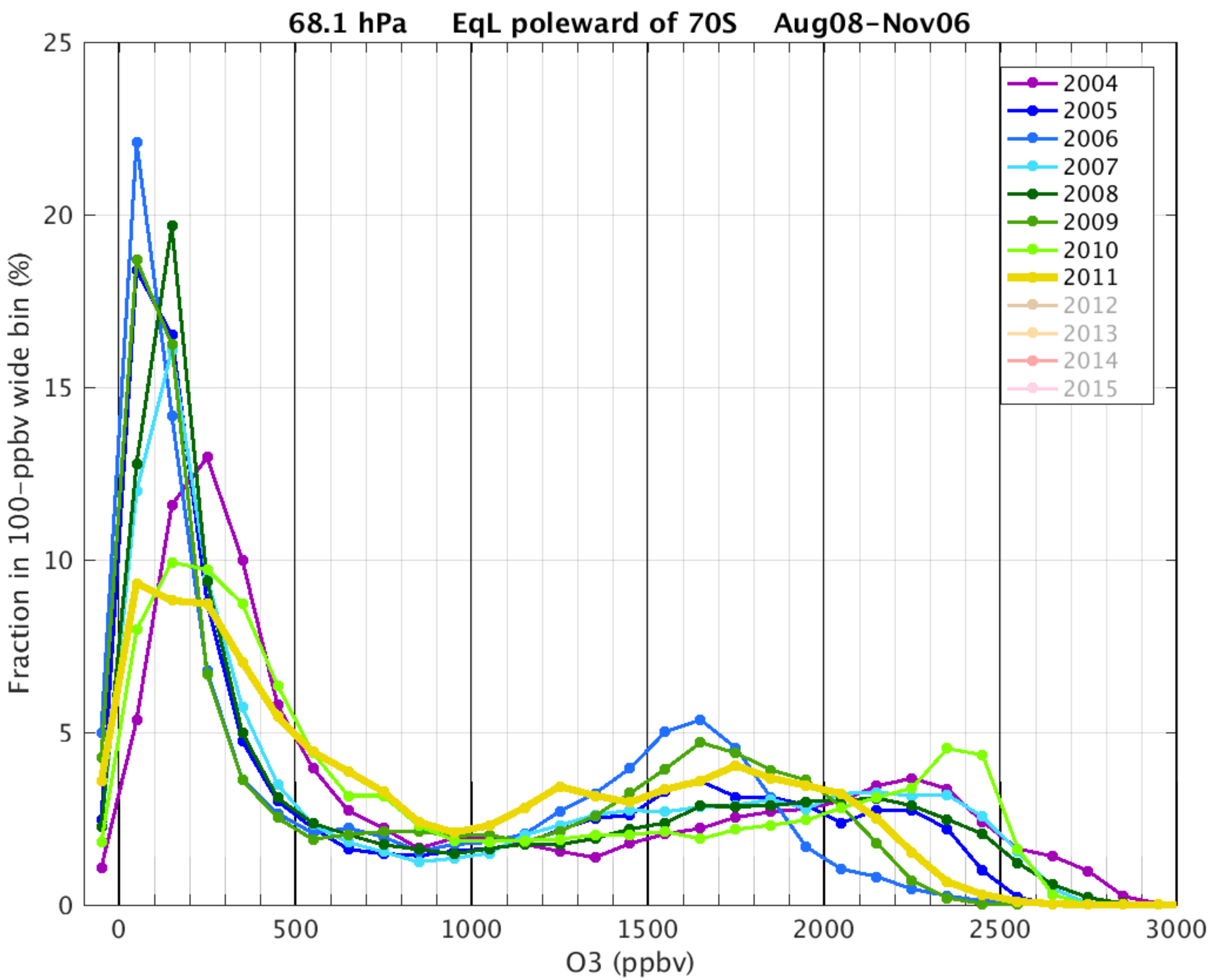
68 hPa Histogram summed over entire 91-day seasonal window

2004 – 2010



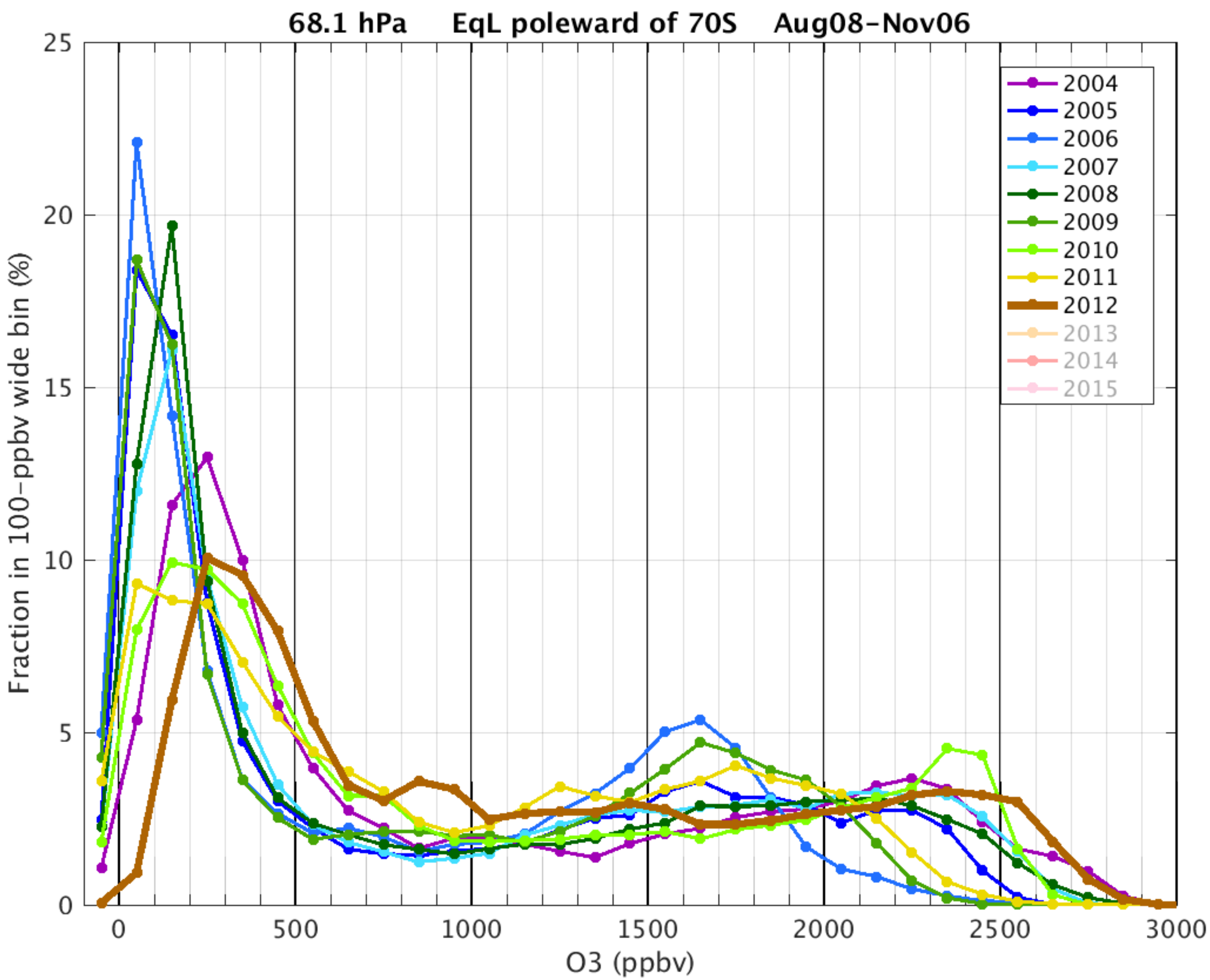
68 hPa Histogram summed over entire 91-day seasonal window

2004 – 2011



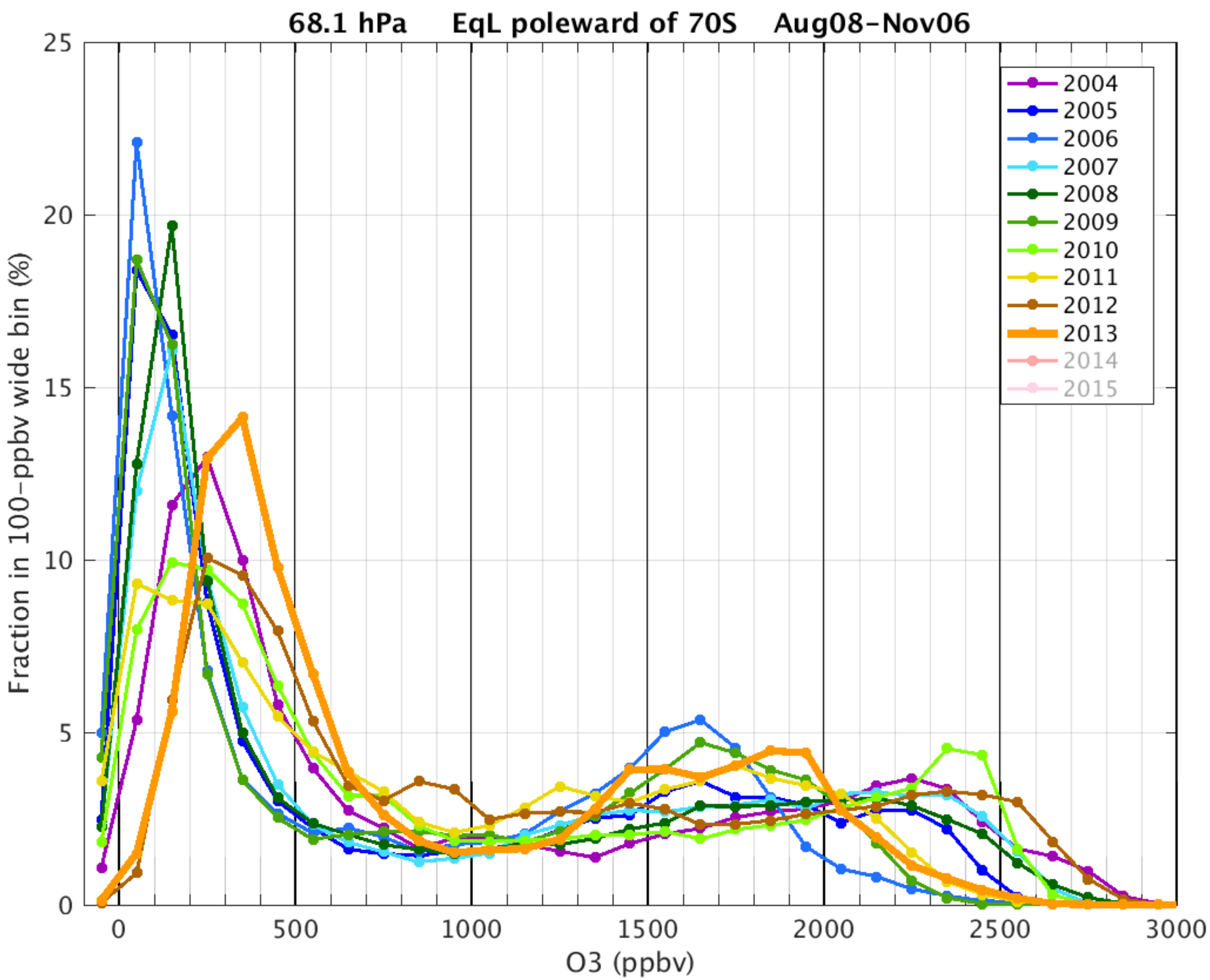
68 hPa Histogram summed over entire 91-day seasonal window

2004 – 2012



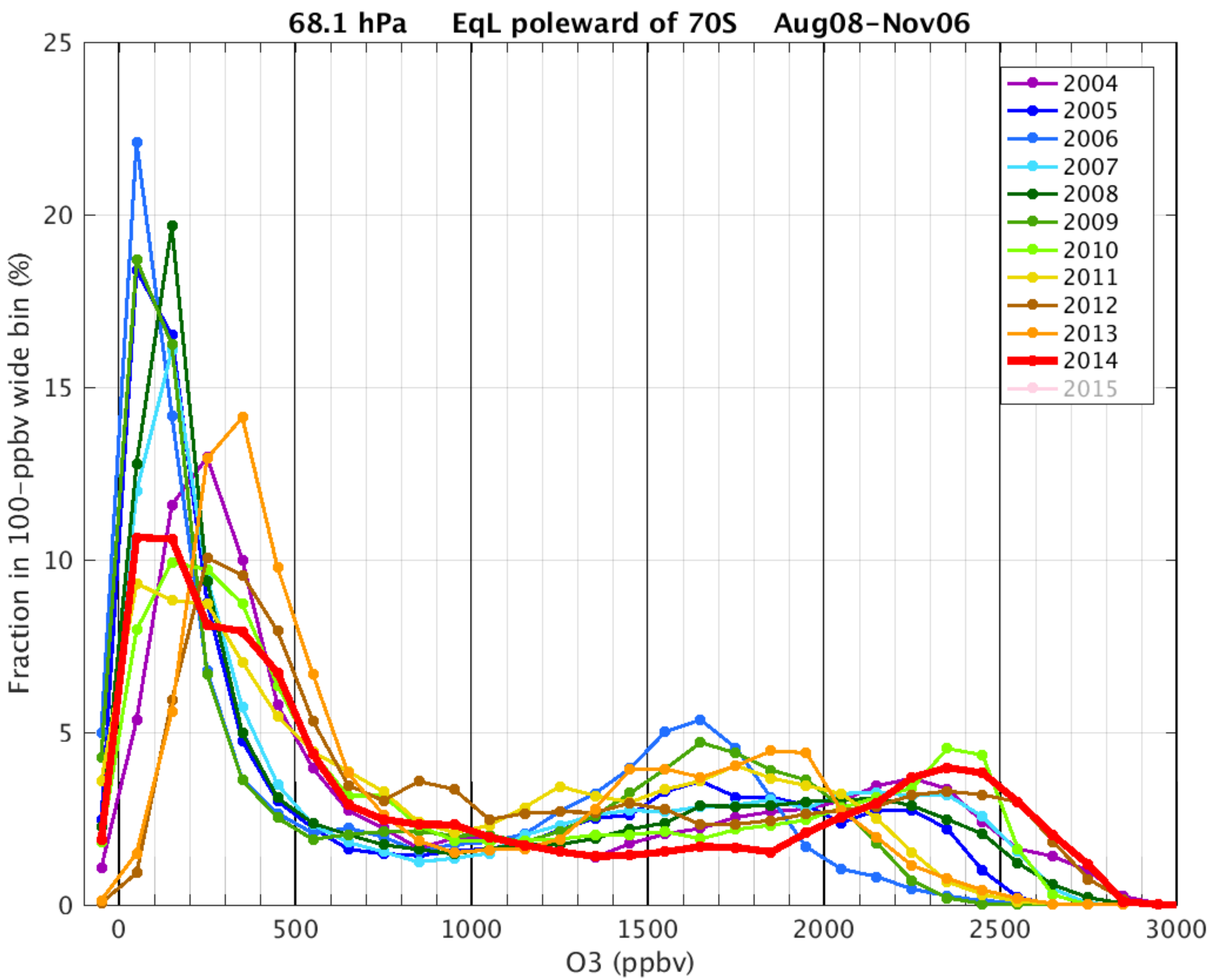
68 hPa Histogram summed over entire 91-day seasonal window

2004 – 2013



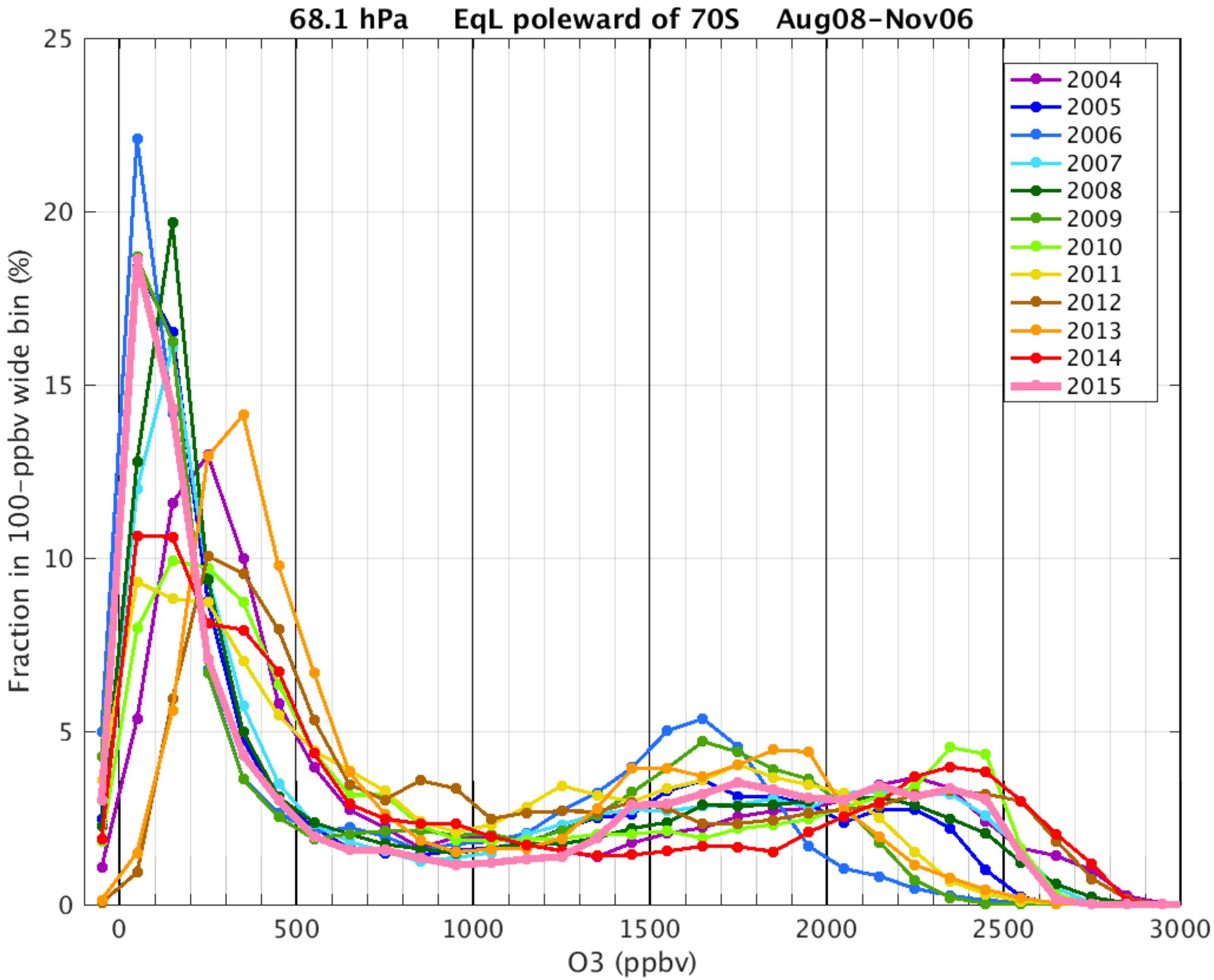
68 hPa Histogram summed over entire 91-day seasonal window

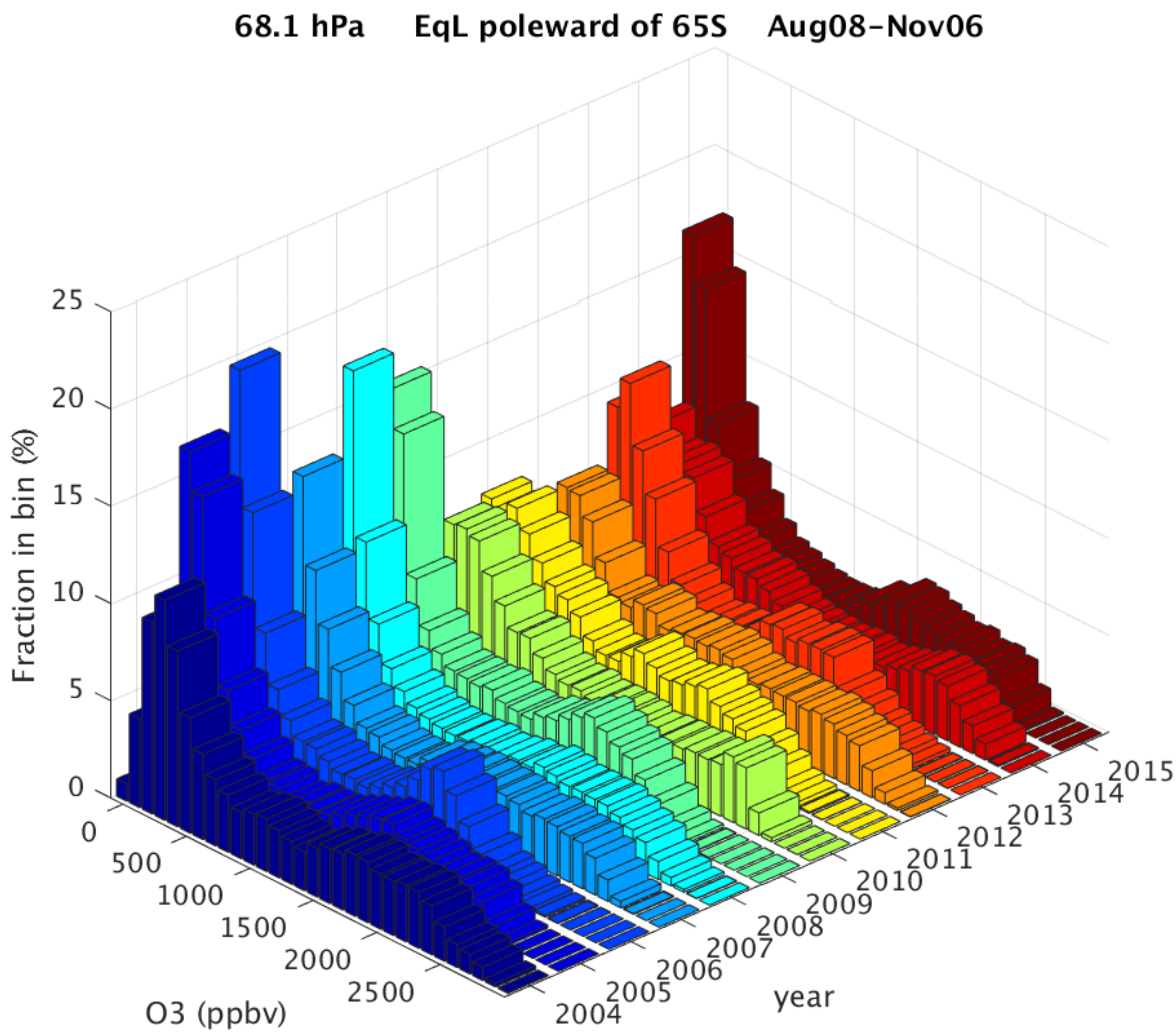
2004 – 2014



68 hPa Histogram summed over entire 91-day seasonal window

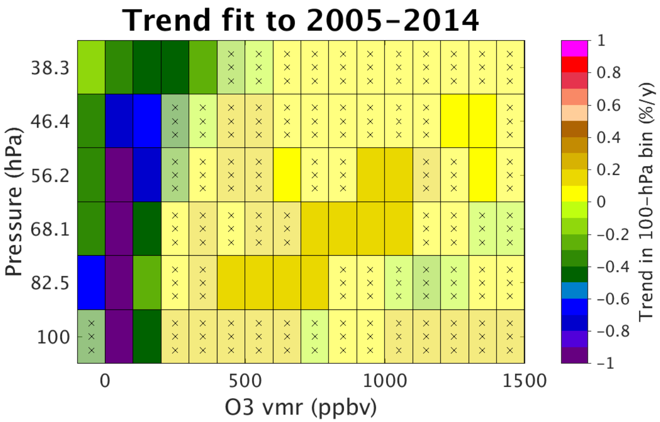
2004 – 2015

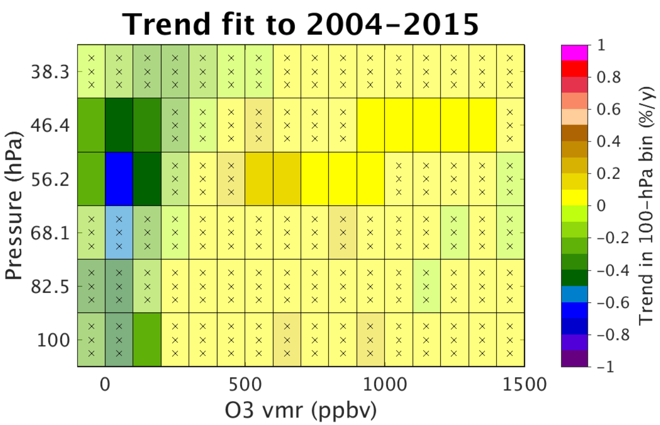



68.1 hPa EqL poleward of 65S Aug08-Nov06
Fraction in bin (%)
0
5
10
15
20
25
O3 (ppbv)
0
500
1000
1500
2000
2500
year
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

Estimated trends are sensitive to the analysis window used

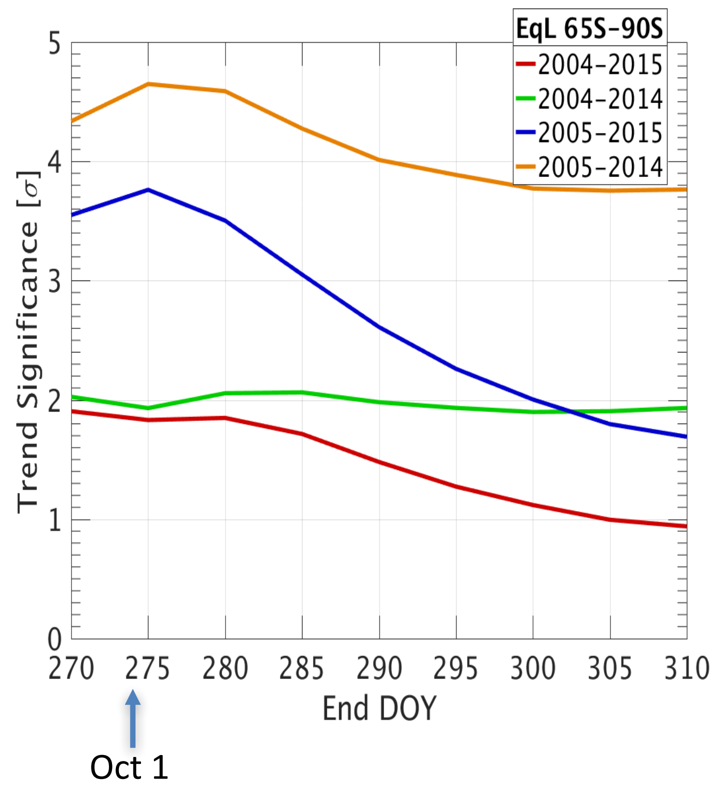
- Trends within each histogram bin were determined for a given ranges of years (all using EqL > 65S, Aug 08 – Oct 07).
- The upper panel, excluding 2004 and 2015, shows trends in the 0–100 ppbv bins exceeding 1% per year at 100–56 hPa, and significant throughout 121–38 hPa (trends > 2 σ from zero are shown with bold colors).
- Population declines in low mixing-ratio bins are balanced by slight increases (<0.2% per year) at ~500–1500 ppbv.
- The lower panel shows trends fit to all 12 years. Even with a short seasonal window reducing the impact of 2015, low-mixing ratio trends are reduced in magnitude (<0.8% per year) and are significant (2-σ) only at 56–46 hPa.
- Volcanic aerosol may contribute to the severity of the 2015 ozone hole, but the 2015 vortex was also exceptionally large and persistently cold through October. In any event, our goal here is to see whether a significant trend can be detected in MLS data against such variability.
- We know of no reason to exclude 2004.





68 hPa, < 100 ppbv trend significance

- Significance of trends in the fraction of mixing ratios < 100 ppbv at 68 hPa (in units of σ) depends strongly upon the range of years and the seasonal window used.
- Seasonal windows all begin in early August (before ozone mixing ratios approach zero) and end from 09/27–11/6 (DOY 270–310).
- When using all 12 years (red), the significance of the trend only approaches 2-σ when the seasonal window is truncated in September.
- Persistent loss in 2015 makes linear fits increasingly poor (red and blue curves) as the seasonal window extends through October.



- When 2004 is included in the range of years (red and green curves), trends barely approach 2 σ for any seasonal window.
- When 2004 is excluded, the significance of the slopes jumps appreciably, exceeding 4-σ when 2015 is also excluded (orange).

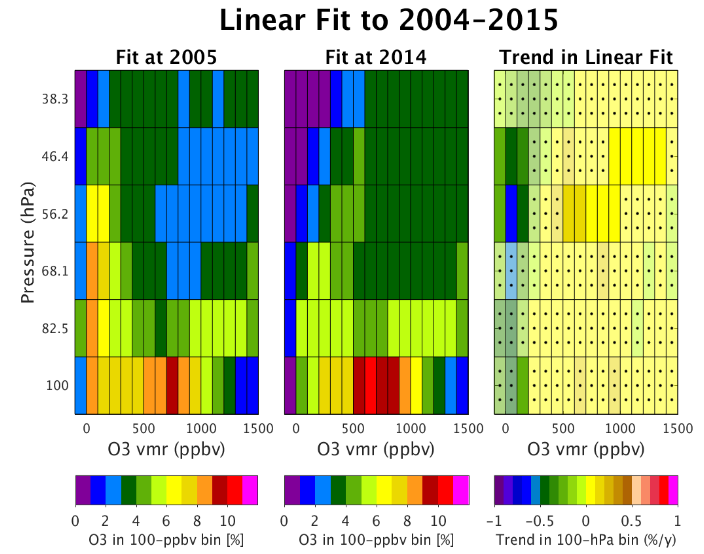
Conclusions and Further Work

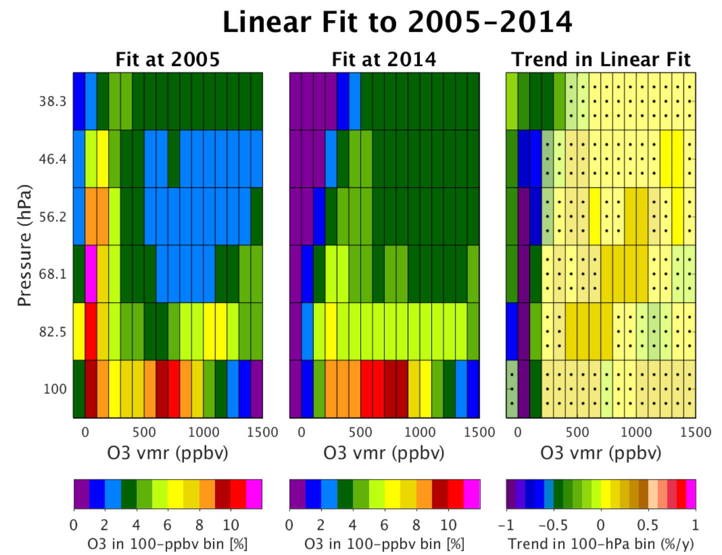
- The 12-year global, daily, vertically resolved MLS record of atmospheric constituents involved in polar ozone chemistry provides a valuable resource for investigation of the Antarctic ozone hole through the beginning of the period where recovery is anticipated.
- The work shown has focused on ozone itself, and the question of whether a significant "healing" trend can be discerned against the backdrop of other sources of variability unrelated to declining ODSs.
- Declining trends in the incidence of very low values (< 100 ppbv) in the Antarctic spring lower stratosphere are apparent to the eye, but are not highly significant (different from zero by > 2 σ) if the entire 12-year record is used.
- We can get a 4-σ trend if we neglect 2004 and 2015, but we lose about half of the significance adding 2004 and another half with the latter part of the seasonal window in 2015.
- We have proposed a plan of future work to more-fully exploit the MLS record to investigate polar ozone trends within the context of both declining ODSs and confounding variability in quantities such as wave forcing; descent rates; mixing; vortex permeability, shape, and sunlit area; volcanic aerosol; and temperature.

Backup Slides

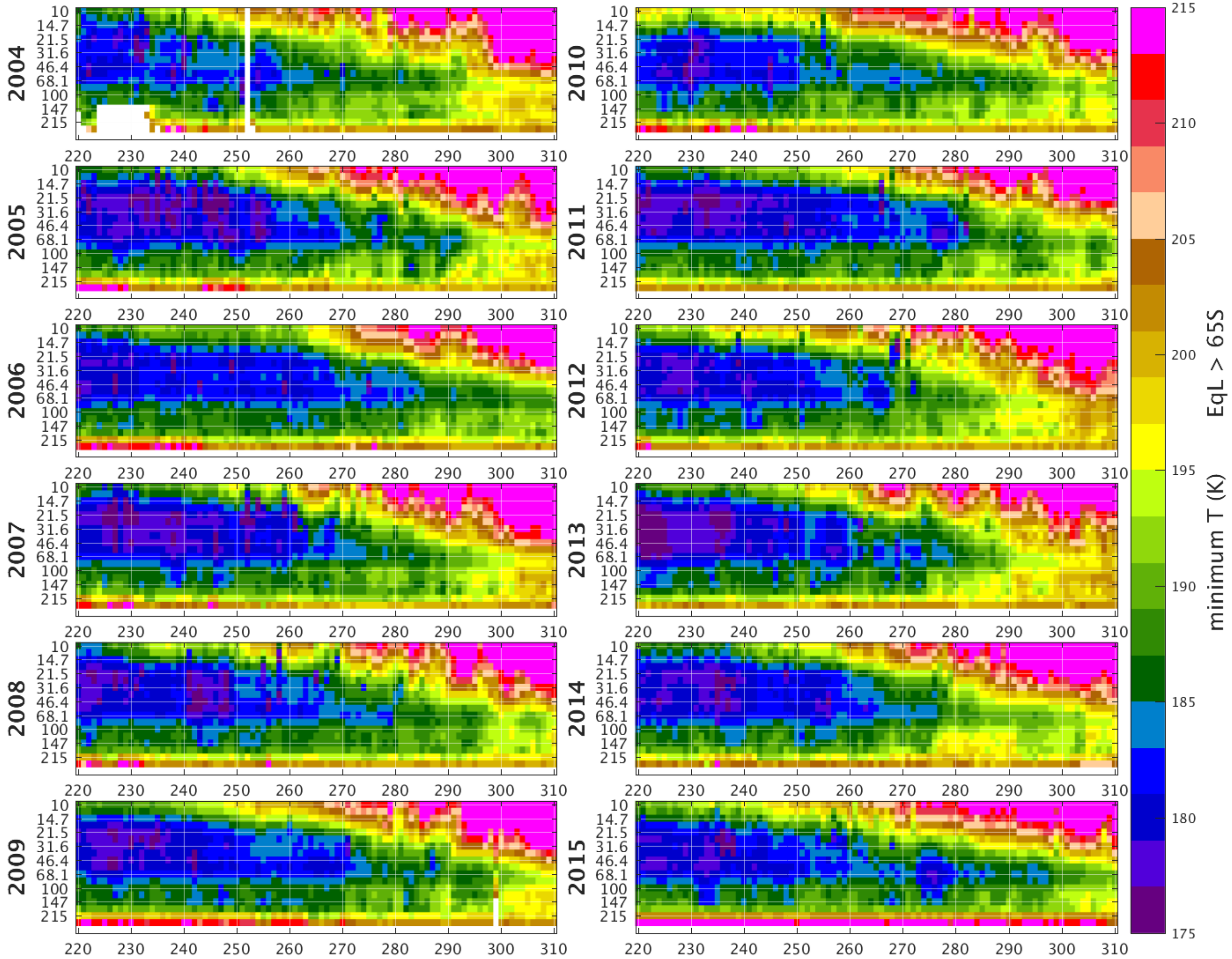
Sensitivity of estimated trends to the analysis window used

- The upper right panel shows the slopes of linear fits to all 12 years of MLS data (EqL > 65S, DOY 220–280) for each 100 ppbv wide bin for each retrieval level. Pale colors with cross hatching indicate fits where the slope differs from zero by less than 2 σ. The left two plots are the fit at 2005 and 2014.
- The incidence of lower stratospheric ozone below 200 ppbv appears to decrease by as much as 0.5% per year, but this result is only significant at 56 hPa and 46 hPa.
- Declines of low values are balanced by slight increases (~0.2 % per year) at ~500–1500 ppbv, but again only significant (2-σ) in limited bins at 46 hPa and 56 hPa.
- The lower plots are analogous, but with years restricted to 2005–2014. The least-squares linear fits to the 0–100 ppbv bins (lower right) have slopes as large as 1 % per year, and are significant nonzero (> 2 σ) from 121–38 hPa.
- We know of no reason to exclude 2004.
- Volcanic aerosol may contribute to the severity of the 2015 ozone hole. The 2015 vortex was also exceptionally large and persistently cold through October. Our goal is to detect a significant trend in MLS data against such variability.

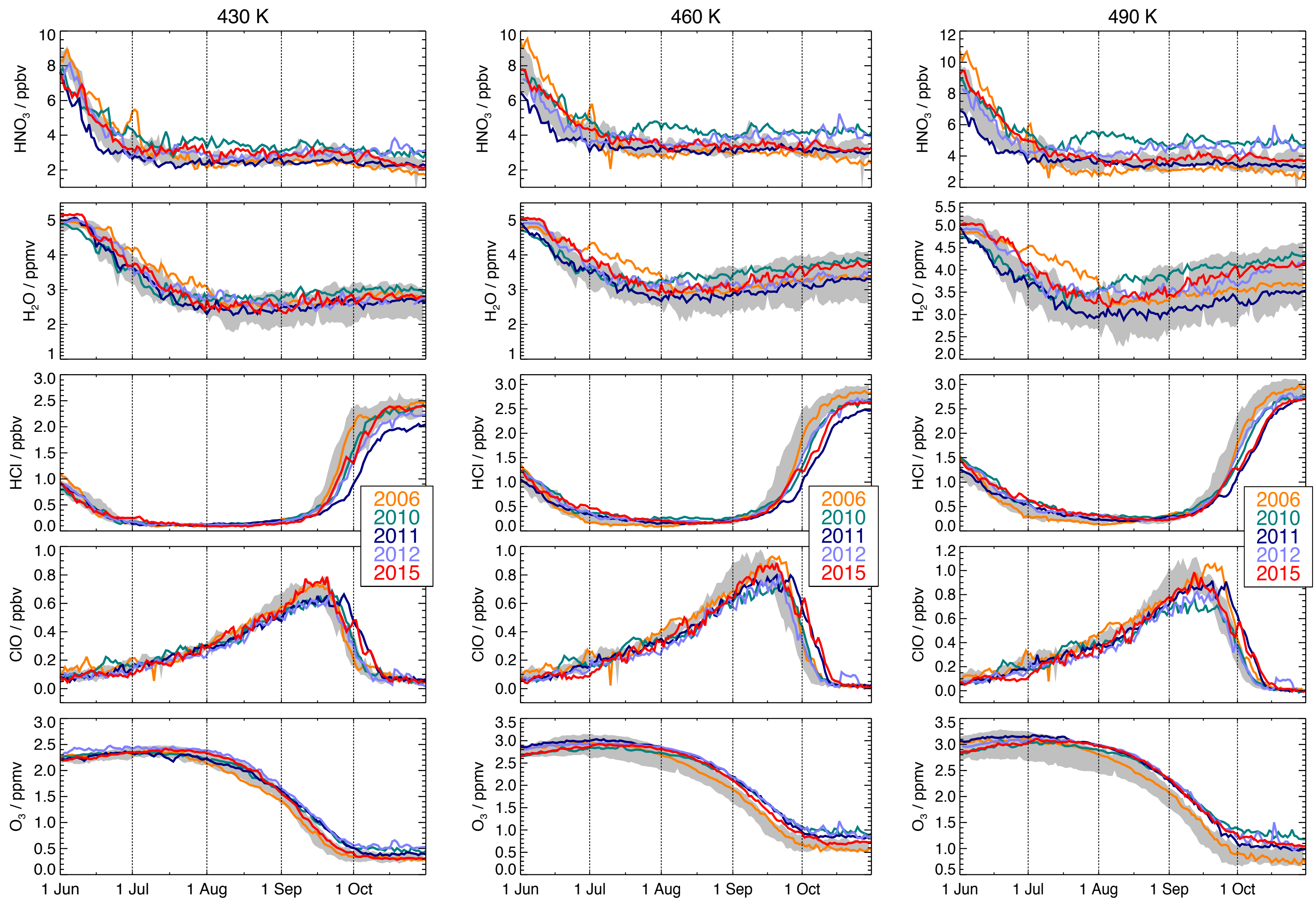




Minimum MLS Temperature   EqL > 65S



MLS Vortex averages



Interannual variability of Dynamical Variables at 460K

Effective diffusivity and the potential Vorticity gradients (top panel) are both metrics of the transport barrier at the vortex edge.